

LESSON 5

TOPIC 1

Slope Stability

SLOPE STABILITY

Lesson 5 - Topic 1

Slide 5-1-1

SLOPE STABILITY

- 1. Compute Resisting & Driving Forces***
- 2. Explain Effects of Water Pressure on Frictional Resistance***

***ACTIVITIES: Circular Arc Analysis
Sliding Block Analysis***

Slide 5-1-2

***Embankments:
Major Design Considerations***

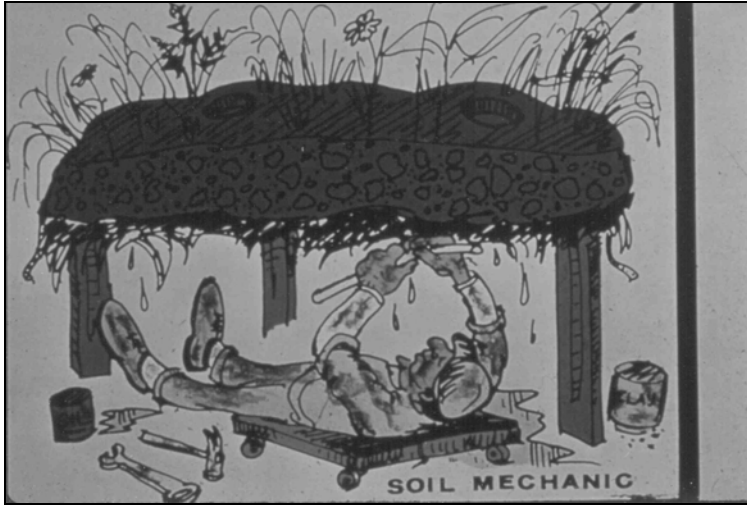
- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 5-1-3

***Embankment Stability
Problem Soils***

- ***Low Strength Clays***
- ***Low Strength Silts***
- ***Peats***
- ***Organic Silts and Organic Clays***
- ***Thin, Weak Seams (Clay, Silt, Sand)***

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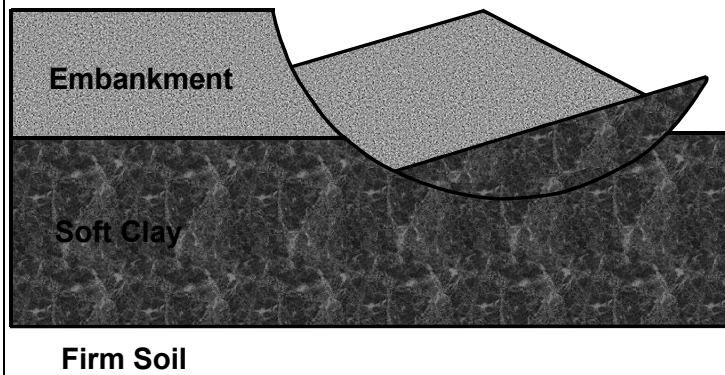


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Major Stability Problems
Circular and Sliding Block Failures

Slide 5-1-6

Circular Arc Failure

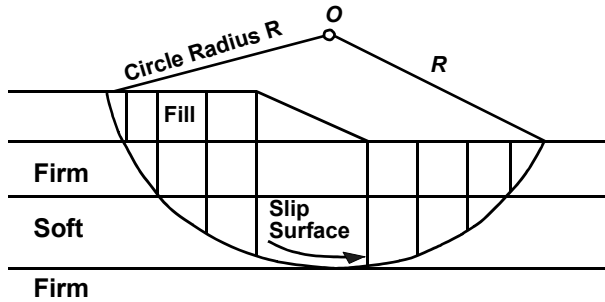


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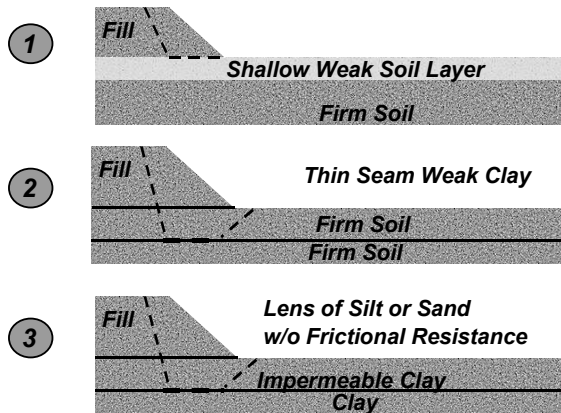
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Circular Arc Stability Analysis



Slide 5-1-9

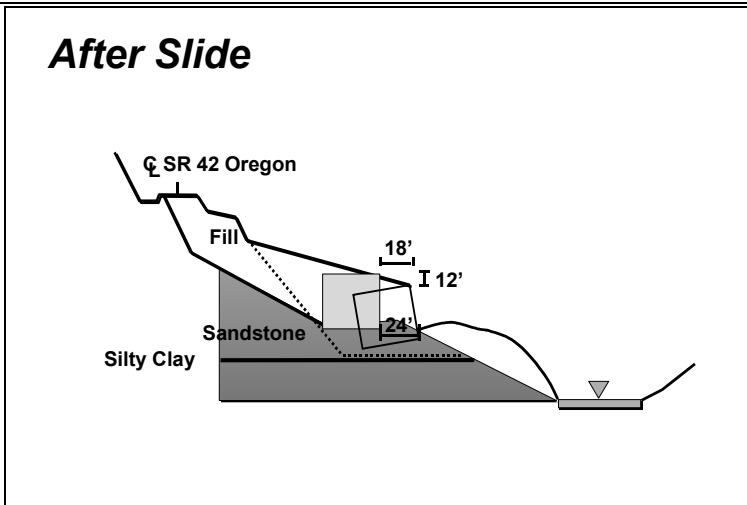
Sliding Block Failure Types



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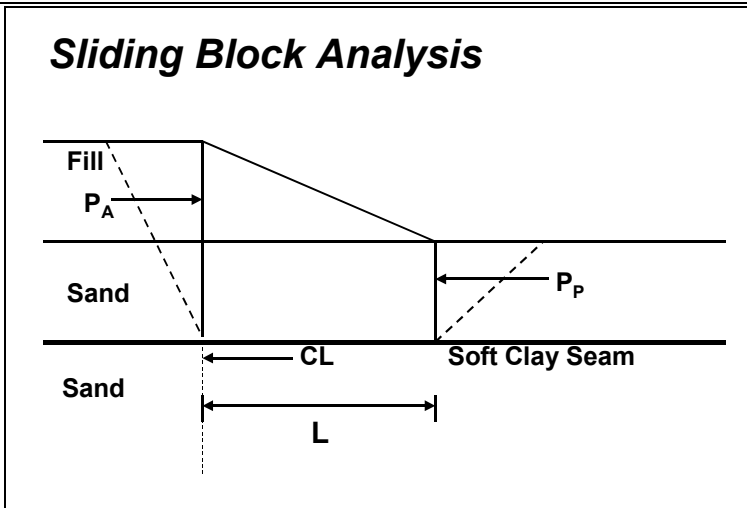
Slide 5-1-11



Slide 5-1-12



Slide 5-1-13



Slide 5-1-14

Effect of Water on Slope Stability

■ Frictional Soils

- *Below Water Table, Buoyancy Reduces Shearing Resistance*

■ Clays

- *Cohesive Strength Decreases as Moisture Content Increases*

Slide 5-1-15

Effect of Water on Slope Stability (Cont'd)

■ Fills on Clays and Silts

- *Soil Consolidates as Water is Squeezed Out - Factor of Safety Increases With Time*

■ Cuts in Clay

- *Soil Absorbs Water When Overburden Pressure Removed - Factor of Safety Decreases With Time*

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Effect of Water on Slope Stability (Cont'd)

- ***Shales, Claystones, Siltstones, Etc.***
 - *Weak Rock Materials “Slake” When Exposed to Water - Embankments Undergo Internal Settlement or Failure*

Slide 5-1-17

Embankments: Recommended Safety Factors

$$\text{Safety Factor} = \frac{\text{Resisting}}{\text{Driving}}$$

- ***End Slope Conditions***
 - *Minimum Safety Factor = 1.30*
- ***Side Slope Conditions***
 - *Minimum Safety Factor = 1.25*

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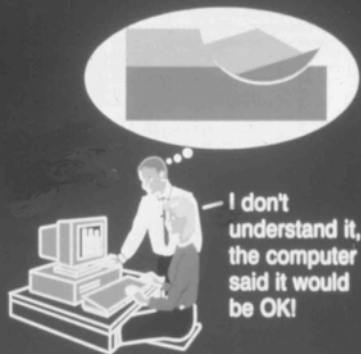
Basis for Selection of Design Safety Factor

- ***Confidence in Subsurface Data (Particularly Soil Strength Value)***
- ***Stability Analysis Method***
- ***Consequences of Failure***

Slide 5-1-19

In DESIGN, put the major emphasis where it belongs:

- Investigation
- Sampling
- Testing
- Soil Profile Development
- Design Soil Strengths
- Water Level Location



Computer programs are only tools which aid us in design - the answers are only as good as the input data. Don't get carried away with plugging in numbers. You may learn the "garbage in - garbage out" principle the hard way.

Slide 5-1-20

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Analysis Methods

- **Rule of Thumb**
- **Hand Solutions**
- **Computer Programs**

Slide 5-1-21

SOILS AND FOUNDATIONS WORKSHOP

$$F.S. = \frac{\Sigma \text{Resisting Moments}}{\Sigma \text{Driving Moments}}$$

$$= \frac{\Sigma N \tan \phi R + \Sigma C R}{\Sigma T R}$$

$$\therefore F.S. = \frac{\Sigma \text{Resisting Forces}}{\Sigma \text{Driving Forces}}$$

$$= \frac{\Sigma N \tan \phi + \Sigma CI}{\Sigma T}$$

Slide 5-1-22

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis for Factor of Safety

The Rule of Thumb is:

$$\text{Factor of Safety (F.S.)} = \frac{6C}{\gamma_{Fill} \times H_{Fill}}$$

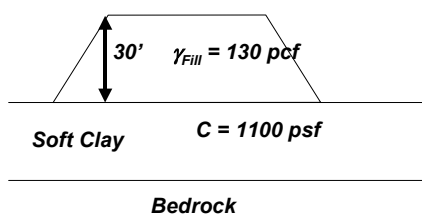
Where: C = Cohesive Strength of Clay (psf)

 γ_{Fill} = Fill Soil Unit Weight (pcf)
$$H_{fill} = \text{Fill Height (ft.)}$$

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SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis Rule of Thumb Example



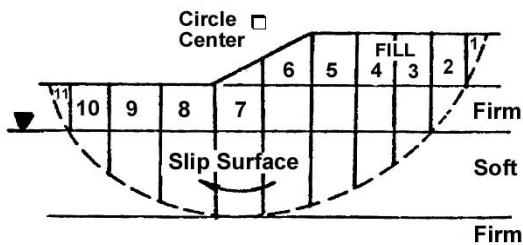
$$F.S. = \frac{(6)(1100)}{(130)(30)} = 1.69$$

Slide 5-1-24

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Normal Method of Slices - Computation by Hand

- 1. Draw Cross Section to Natural Scale**
- 2. Select Failure Surface**
- 3. Divide Mass into 10-15 Vertical Slices**



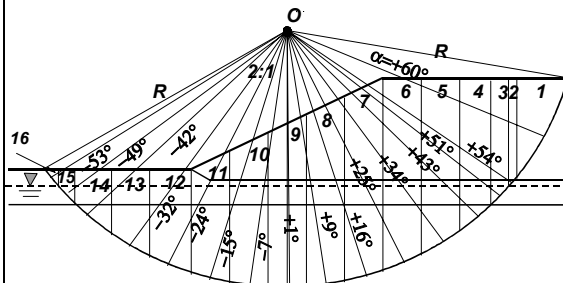
Slide 5-1-25

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SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis

Extend rays from circle center “O” to the failure surface at the projected centroid of each slice



Note that slices 1 through 9 have positive α angles and contribute to the driving force. Slices 10 through 16 have negative α angles and reduce the net driving force.

Slide 5-1-26

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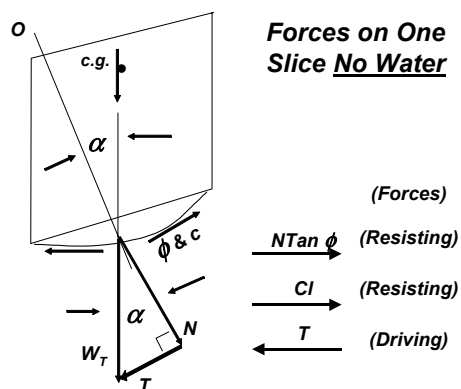
SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Computation by Hand

4. **Compute Total Weight (W_T) of Each Slice**
5. **Compute Resisting Forces: $N \tan \phi - \mu l$ (Frictional) and $C l$ (Cohesive) for Each Slice**
6. **Compute the Tangential Driving Force (T).**

Slide 5-1-27

SOILS AND FOUNDATIONS WORKSHOP



C = Cohesion along slice base

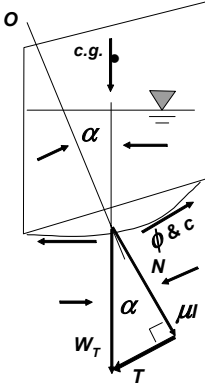
$\tan \phi$ = Coefficient of friction along slice base

W_T = Total slice weight

$$T = W_T \sin \alpha$$
$$N = W_T \cos \alpha$$

Slide 5-1-28

SOILS AND FOUNDATIONS WORKSHOP



Forces on One Slice With Water

	(Forces)
$\xrightarrow{N \tan \phi}$	(Resisting)
$\xrightarrow{C l}$	(Resisting)
\xleftarrow{T}	(Driving)

μ = Water pressure on slice base
= Avg. $h_{\text{water}} \times \gamma_w$

μl = Water uplift force

W_T = Total slice weight
(use γ_{Total} both above and below W.T.)

Note $\rightarrow N = W_T \cos \alpha$ μl

$T = W_T \sin \alpha$

Slide 5-1-29

[illegible]

SOILS AND FOUNDATIONS
WORKSHOP

***Normal Method of Slices -
Computation by Hand***

***7. Sum Resisting and
Driving Forces for All
Slices and Compute
Safety Factor (F.S.)***

Slide 5-1-30

[illegible]

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example for One Slice with No Water

Assume:

- $\gamma_{\text{total}} = 120 \text{ pcf}$, slice height = 10', slice width = 10', $\phi = 25^\circ$, $\alpha = 20^\circ$, $l = 11'$, $C = 200 \text{ psf}$.
- Find: Resisting and Driving Forces

Slide 5-1-31

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution

$$\begin{aligned} W_T &= \gamma_{total} \times \text{slice area (x} \\ &\quad \text{1' thick)} \\ &= 120 \text{ pcf} \times 10' \times 10' \\ &= 12000 \text{ lbs} \end{aligned}$$

$$\begin{aligned} N &= W_T \cos \alpha - \mu l \\ &= 12000 \text{ lbs} \times \cos 20^\circ \\ &= 11276 \text{ lbs} \end{aligned}$$

Slide 5-1-32

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution (Cont'd)

$$N \tan \phi = 11276 \times \tan 25^\circ$$

$$= 5258 \text{ lbs}$$

$$CI = 200 \text{ psf} \times 11' \times 1' = 2200 \text{ lbs}$$

$$\begin{aligned} T &= W_t \sin \alpha \\ &= 12000 \text{ lbs} \times \sin 20^\circ \\ &= 4104 \text{ lbs} \end{aligned}$$

Slide 5-1-33

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices Group Exercise

Assuming the water is 5' above the slice base, which of the force components change in this exercise?

Slide 5-1-34

SOILS AND FOUNDATIONS
WORKSHOP

Sliding Block Failure Analysis Methods

- *Hand Solution*
- *Computer Solution*

Slide 5-1-35

SOILS AND FOUNDATIONS
WORKSHOP

SLIDING BLOCK ANALYSIS

The diagram illustrates the sliding block analysis of a retaining wall. It shows a cross-section with a wall on the left. The soil behind the wall is divided into three regions: the Active Wedge (left), the Central Block (middle), and the Passive Wedge (right). The wall is subjected to a horizontal force P_A (Active Pressure) and a horizontal force P_P (Passive Pressure). The wall is embedded in a soil layer of thickness L . The soil is composed of Sand and a Soft Clay Seam. The distance from the wall face to the center of the clay seam is labeled CL . The wall is shown on a foundation of Sand.

Slide 5-1-36

SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure

The diagram illustrates the active earth pressure on a retaining wall. On the left, a vertical line represents the ground surface, with a downward arrow labeled z indicating depth and an upward arrow labeled H indicating the total height. A horizontal arrow labeled P_A points to the right, representing the resultant active force. To the right of the ground surface, a triangular distribution of pressure is shown, with horizontal arrows of increasing length from top to bottom, labeled p_a at the base. The retaining wall is depicted as a vertical structure on the right, with a base that extends to the right.

$$P_a = K_A \gamma z$$
$$PA = \frac{1}{2} \gamma H^2 K_A \text{ (Active Force)}$$

Slide 5-1-37

[illegible]

The diagram illustrates the forces acting on a central block in a soil wedge failure. A vertical arrow labeled P_A points downwards from the top of the block, representing the weight of the soil wedge. A horizontal arrow labeled P_A points to the right from the center of the block, representing the active earth pressure. A diagonal line represents the failure plane, with arrows pointing away from the block along its length, labeled "Resistance Along Failure Plane (due to soil strength)". The angle between the failure plane and the horizontal is labeled $45 - \phi/2$.

Wedge Failure Plane

Resistance Along Failure Plane (due to soil strength)

$45 - \phi/2$

$P_A = \text{Net Force Against the Central Block}$

$P_A = 1/2 \gamma H^2 K_A \text{ (Active Force)}$

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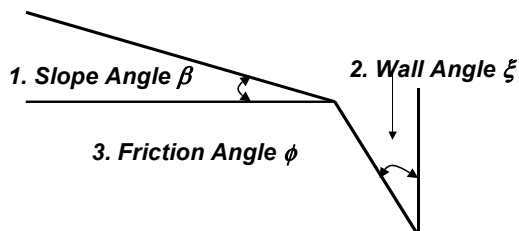
SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure

$$K_A = \tan^2(45 - \phi/2)$$

(For $\beta = 0, \xi = 0$)

K_A varies with:

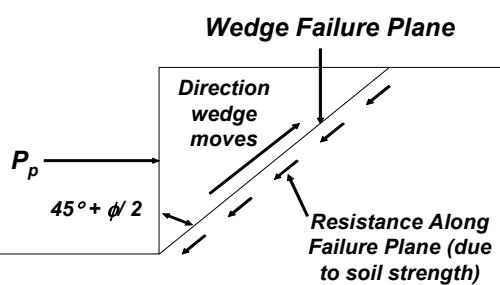


If ξ or $\beta \neq 0$, compute K_A from formulas or charts in soils textbooks

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SOILS AND FOUNDATIONS WORKSHOP

Passive Earth Pressure



$P_p = \underline{\text{Passive Force}}$

$$P_p = \frac{1}{2} \gamma H^2 K_p$$

$$K_p = \tan 2(45^\circ + \phi/2)$$

(If $\beta = 0, \xi = 0$)

Slide 5-1-40

SOILS AND FOUNDATIONS
WORKSHOP

SLIDING BLOCK ANALYSIS

P_A = Active Driving Force = $\frac{1}{2} \gamma H^2 K_A$
 P_P = Passive Resisting Force = $\frac{1}{2} \gamma H^2 K_P$
 CL = Resisting Force Due To Clay Cohesion

$F.S. = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{P_P + CL}{P_A}$

Slide 5-1-41

SOILS AND FOUNDATIONS
WORKSHOP

Example 5.1: Find the Safety Factor For The 20' High Embankment By The Simple Sliding Block Method Using Rankine Pressure Coefficients, for the Slope Shown Below.

$\gamma_T = 110 \text{ pcf}$
 $\phi = 30^\circ$

$\gamma_T = 110 \text{ pcf}$
 $\phi = 30^\circ$

Soft Clay $C = 400 \text{ psf}$

Firm Material

Slide 5-1-42

SOILS AND FOUNDATIONS WORKSHOP

Solution:

Step 1: Compute Driving Force (P_A)

- **Active Driving Force (P_a)** (consider a 1 ft. wide strip of the embankment)

$$P_A = \frac{1}{2} \gamma_T H^2 K_A$$

(Use γ_T as the water table is below the failure plane)

$$K_A = \tan^2 \left(45 - \frac{\phi}{2} \right) = \tan^2 \left(45 - \frac{30}{2} \right) = 0.33$$

$$P_A = \frac{1}{2} (0.110 \text{ kcf}) (30')^2 (0.33) (1') = 16.5 K$$

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SOILS AND FOUNDATIONS WORKSHOP

Solution (cont'd):

Step 2: Compute Resisting Force (C_I & P_p)

- **Central Block Resistance (CI)**

$$CI = (0.400 \text{ ksf})(40')(1') = 16.0 K$$

- **Passive Resisting Force (P_p)**

$$P_p = \frac{1}{2} \gamma_T H^2 K_p$$

$$K_p = \tan^2(45 + \frac{\phi}{2}) = \tan^2(45 + \frac{30}{2}) = 3.0$$

$$P_p = \left(\frac{1}{2}\right)(0.110 \text{ kcf})(10)^2(3.0)(1') = 16.5K$$

$$\text{Safety Factor} = \frac{C_I + P_p}{P_A} = \frac{16.0K + 16.5K}{16.5K} = 1.97$$

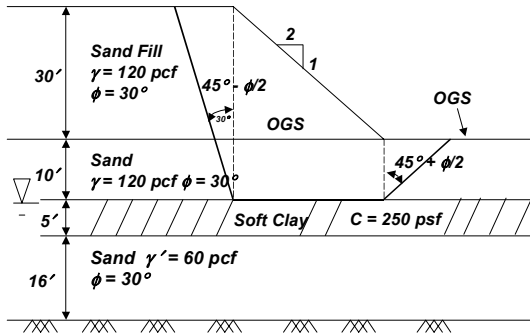
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SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 2

Sliding Block Analysis

(1) Using a Rankine sliding block analysis, determine the safety factor against sliding for the embankment and assumed failure surface shown.



(2) EFFECT OF RISE IN WATER TABLE: Consider the changes in resisting and driving forces in Part 1 assuming that water table rises 10' to the original ground surface.

Slide 5-1-45

SOILS AND FOUNDATIONS WORKSHOP

Slope Stability

- **Compute Resisting and Driving forces**
- **Explain the Effects of Water Pressure on Frictional Resistance**

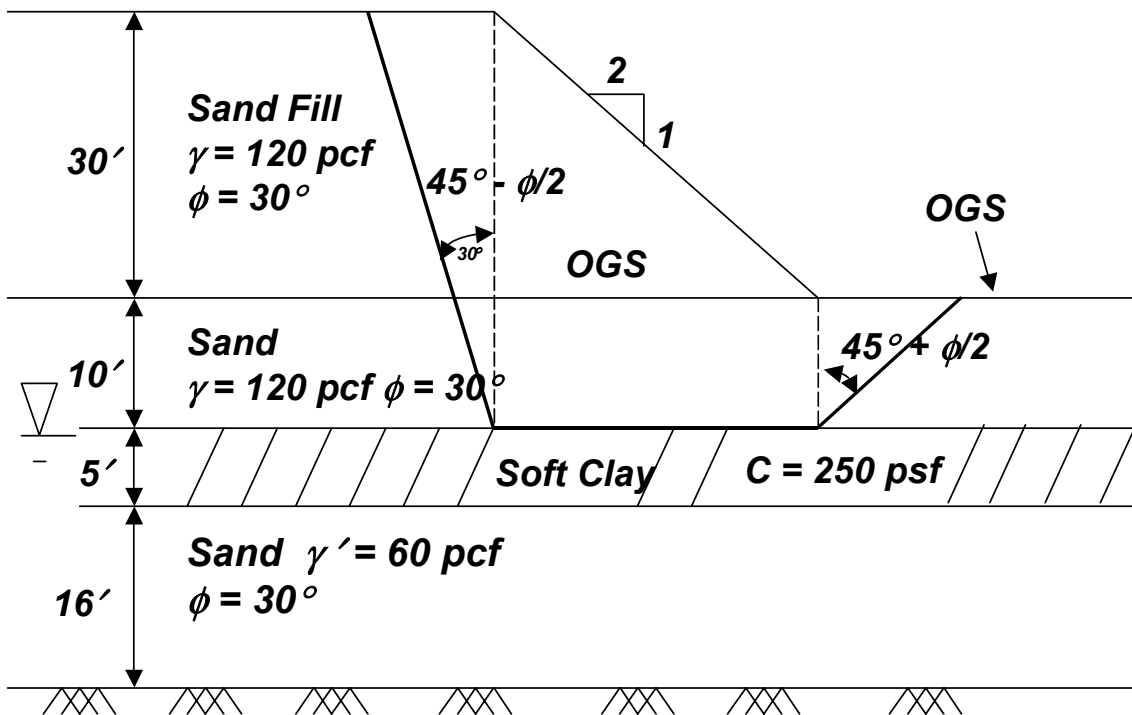
Activities: *Circular Arc*
Sliding Block

Slide 5-1-46

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 2 Sliding Block Analysis

(1) Using a Rankine sliding block analysis, determine the safety factor against sliding for the embankment and assumed failure surface shown.



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